OPTIMIZING SECONDARY ROOF SUPPORT WITH THE NIOSH SUPPORT TECHNOLOGY OPTIMIZATION PROGRAM (STOP)

By Thomas M. Barczak[1]

ABSTRACT

The 1990s brought an unprecedented increase in the development of innovative technologies to provide more effective and easier-to-install roof support in underground mines. To facilitate the application of these technologies in improving mine safety, the National Institute for Occupational Safety and Health (NIOSH) developed the Support Technology Optimization Program (STOP). STOP is a Windows-based software program that provides mine operators with a simple and practical tool to make engineering decisions about the selection and placement of these various roof support technologies. The program includes a complete database of the support characteristics and loading profiles obtained through safety performance testing of these supports at the NIOSH Safety Structures Testing Laboratory. A support design criterion in the form of the required support load density at a specified convergence can be established from four options: (1) a database of measured ground reaction obtained from various mines or ground behavior information input by the user, (2) load requirements based on a detached roof block or rock failure height, (3) criteria based on the current roof support system, and/or (4) arbitrary criteria set by the user. Using these design criteria, the program will determine the installation requirements for a particular support technology that will provide the necessary support load density and convergence control. Optimization routines are also available to determine the most efficient support design for a user-specified support installation. In addition to these performance measures, STOP can be used to compare material handling requirements and installation costs. Comparisons among the various support technologies are easily made, including a graphical analysis of relevant support parameters. This paper describes STOP and its application to optimizing standing secondary roof support systems.

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INTRODUCTION

Secondary support provides additional roof support in the event of failure of the primary support system. When properly designed, secondary support will also assist the primary support in controlling the integrity of the immediate roof beam. Thus, roof support should be thought of as a three-part system: (1) the remaining coal pillars, which provide control of overburden weight, (2) the primary support system consisting of roof bolts, which help form a more competent roof beam and, in the case of mechanical bolts, attach the immediate roof beam in suspension to the more stable main roof rock, and (3) the secondary roof support system, which consists of standing roof support and intrinsic support elements designed to control deformation of the immediate roof and handle additional abutment loads during retreat mining. The latter occurs in longwall mining where the tailgate is frequently supported with various secondary roof support systems. It should be noted that the Support Technology Optimization Program (STOP) in its present form is limited to the evaluation of standing roof support systems.

Engineering design is applied primarily to size the pillars to account for load variations due to depth of cover, active mining zones, and the quality of the roof rock. Computer programs such as the Analysis of Longwall Pillar Stability (ALPS) and Analysis of Retreat Mining Pillar Stability (ARMPS) programs are valuable tools in designing pillars for various mining scenarios [Mark 1992; Mark and Chase 1997]. There are no universally accepted design criteria for primary support (roof bolts), although recent research by the National Institute for Occupational Safety and Health (NIOSH) indicates that there may be some fundamental criteria to define conditions where current primary support densities are inadequate. The Wood Crib Performance Model [Barczak and Gearhart 1993] was developed by the former U.S. Bureau of Mines in 1994 to provide engineering design for conventional wood cribs, which were the predominant form of secondary support at the time. The Wood Crib Performance Model was used to determine the supporting capability of various conventional wood crib configurations and match this capability to user-defined load and convergence criteria. More recently, a design methodology for standing secondary roof support in longwall tailgates was developed that incorporates measured ground reaction data into the formulation of the load and convergence design criteria for standing roof support systems [Mucho et al. 1999; Barczak et al. 1999].

In the past 5 years, there have been 16 new standing roof support systems developed for use as secondary roof support. These new support systems not only provide superior roof support, but many provide material handling advantages as well. STOP was developed by NIOSH to allow mine operators to compare these various support systems and to optimize the application of both new standing roof support technologies and conventional wood and concrete crib support systems. Although STOP can be considered as an upgrade of the original Wood Crib Performance Model, it is built on a Windows-based architecture and has several enhanced features that were not available in the previous Wood Crib Performance Model. These include—

(1) Selection from a database of currently available standing roof support systems for evaluation;

(2) A synopsis of pertinent design and installation criteria for each support system;

(3) A description of performance characteristics, including photographs of the support loading profile showing the condition of the support as it deforms;

(4) Name and telephone numbers for support manufacturers;

(5) Ground reaction curve support design criteria where the laboratory support performance can be matched to a curve corresponding to ground behavior, as opposed to a single (load and convergence) data point, as was done in the original Wood Crib Performance Model;

(6) Enhanced optimization algorithms that determine the most sufficient support design for user-specified spacing limitations and/or the user-defined load density and convergence requirements;

(7) Material handling and cost information for each support; and

(8) graphical displays of support system capabilities.

It is important to understand that although there are now a wide variety of support choices, each of these support systems has a unique performance profile. Simply replacing one support system with another will not provide equivalent ground control. Most of the new support technologies provide superior supporting capability, which may allow wider spacings of the support to be used if the goal is to provide support capability equivalent to that of a conventional wood crib support system. STOP will determine the spacing requirements that will provide equivalent support capacity. This is one way that STOP can optimize the use of a particular support system. STOP can also provide important information regarding the benefits of increasing support load density. Using measured ground reaction data, STOP will determine either the convergence that can be expected from a certain support design installed on user-selected spacings or the support spacing required to limit convergence to a certain level.

This information can be very useful when petitioning the Mine Safety and Health Administration (MSHA) for approval to use an alternative support technology. Without this information, MSHA will typically require a trial section where the alternative support system can be observed before full approval is granted. In longwall mining, this means that a mine operator might have to wait for a full panel of mining before implementing a new support technology. Likewise, without an engineering basis to justify a change, variations in placement strategy or implementing a change in support design can be delayed until a trial section is observed. Thus, STOP can be included as another part of the overall process that MSHA may use in approving a roof support plan. While it may not be the sole deciding factor, STOP can provide critical engineering data that will facilitate a decision regarding the implementation of these new support technologies.

This paper introduces STOP, describes the architecture of the program, and provides several examples of how it can be used to optimize the design and use of secondary roof support technologies. STOP can provide an engineering foundation to ensure that inadequate support designs, as well as ultra-conservative support applications, are avoided. Safety will be improved by proper matching of support performance to mine conditions, which will reduce the likelihood of roof falls and blocked escapeways. Material handling injuries associated with support construction are known to account for about 5,000 lost workdays per year in underground coal mines. STOP can help to define the material handling advantages of alternative support technologies that use lighter weight materials or systems that can be installed with mechanical assist. The use of these support technologies can significantly reduce material handling injuries.

PROGRAM ARCHITECTURE

STOP is a Windows-based architecture. The Main Menu allows the user to control the flow through the program if desired. This window can be accessed through each of the primary program segments. The Main Menu contains six modules: File, Design Criteria, Support Evaluation, Comparison, Information, and Help.

File: The *File* module contains file management subroutines that allow the user to create new files, open and close existing files, and exit from the program. The File menu also allows the user to set the path for storing several photographs that are incorporated into the program to allow visual display of support performance.

Design Criteria: The *Design Criteria* module is where the load and convergence design criteria for the support system are formulated. The requirement is to define the required support load density in terms of tons of support capacity per linear foot of entry advance and at what convergence this support capability is to be provided. There are four different ways to establish these design criteria in the program: (1) ground reaction curve, (2) detached block, (3) current support system, and (4) arbitrary criteria.

1. *Ground Reaction Curve* (figure 1) allows the user to define support load density and convergence criteria from in-mine measurements of the ground behavior (convergence) associated with various support systems [Mucho et al. 1999; Barczak et al. 1999]. Essentially, the ground reaction concept implies that convergence in the mine entry is controlled by the magnitude of support resistance. Generally, convergence decreases with increasing support load density. Thus, if measurements of convergence are made with two or more support systems of varying stiffness, then a ground reaction curve can be established for that particular mine. The user can define a ground reaction curve or use one from the database established from various mine sites maintained in the program. Once a ground reaction curve is defined, the program will determine the required spacing for a particular support system that will provide the support load density consistent with the ground reaction curve at a specified convergence.

2. *Detached Block* is shown in figure 2. The support load density requirements are established by calculating the weight of a detached block of roof rock above the mine entry. The failure height can be inputted by the user or estimated from the quality of the roof rock (Coal Mine Roof Rating) using an approximation developed by Unal [1986]. The volume of the block is also influenced by the shape of the failure. Options include either an arch or a vertical shear failure at the pillar boundaries. Two options are available for determining the convergence criteria. If ground reaction information is available, this information can be used to help define the convergence criteria. In terms of the ground reaction curve, there is a critical convergence where failure of the roof occurs. This could be used to define the convergence criteria for the detached block, the idea being that the support should put the roof rock mass into equilibrium before the critical convergence is reached. If this option is selected, convergence is defaulted to the maximum convergence on the ground reaction curve, but the user can change this input if desired. In the absence of ground reaction information, the user can simply input a convergence criteria (allowable displacement before roof weight is supported in equilibrium).

3. *Current Support System* allows the user to define design requirements based on the performance of the current support system (figure 3). Two options are available. The first one is that if a ground reaction curve is available, then the program will determine where the current support system falls on the ground reaction curve and set the support load density and convergence requirements to that point. For the second option, the user must define an allowable convergence, which should be based on some in-mine measurements. The support capacity and resulting load density for support spacing will be calculated from the load-displacement profile for the support, as

determined from tests in the Pittsburgh Research Laboratory's (PRL) unique Mine Roof Simulator load frame or from other laboratory data.

4. *Arbitrary Criteria* simply allows the user to set the support load density and convergence criteria to any arbitrary set of values.

***Support Evaluation**:* The *Support Evaluation* module is the heart of the support design process. Any of a variety of support systems contained in the program database can be selected for design and analysis (figure 4). The *Design* algorithm calls up a subroutine that allows the user to control relevant design parameters and/or pick from the available design (models) for a particular support type (figure 5). The user must also input the number of rows to be used in the support placement. The program will then calculate the required spacing of the supports to achieve the desired support load density at the designated convergence, or the user can select a support spacing and the achieved convergence will then be calculated for the user-defined support installation. An optimization algorithm is also included in which the program will determine the support design or model that most closely matches the design criteria (support load density at designated convergence). Also included in the *Support Evaluation* module are analyses of installed support costs and material handling requirements for the support.

Comparison: The *Comparison* module compares the support systems chosen for analysis. There are three windows in the Comparison module: (1) *Comparison Assessment Table*, (2) *Support Description Summary*, and (3) *Graphical Data Analysis*. The *Comparison Assessment Table* describes the support layout (number of rows and support spacing) and various design parameters for each support system in a tabular format. The parameters are grouped into six categories: (1) support layout, (2) ground control, (3) unit support costs, (4) normalized support cost, (5) installation assessment, and (6) material handling. The user can pick any one of the selected support systems as a baseline system for comparison purposes. The *Support Description Summary* summarizes the support design parameters for each support system. The *Graphical Data Analysis* window allows the user to plot support performance (unit support load or support load density) as a function of convergence and graphically compare the various support systems, as shown in the example in figure 6. Ground reaction data can also be displayed on the plots to show the convergence control provided by the various support systems relative to the ground reaction curve.

Information: The *Information* module can be thought of as a general information center. The various support technologies are categorized in six groups: (1) conventional wood (crib) supports, (2) engineered timber supports, (3) conventional

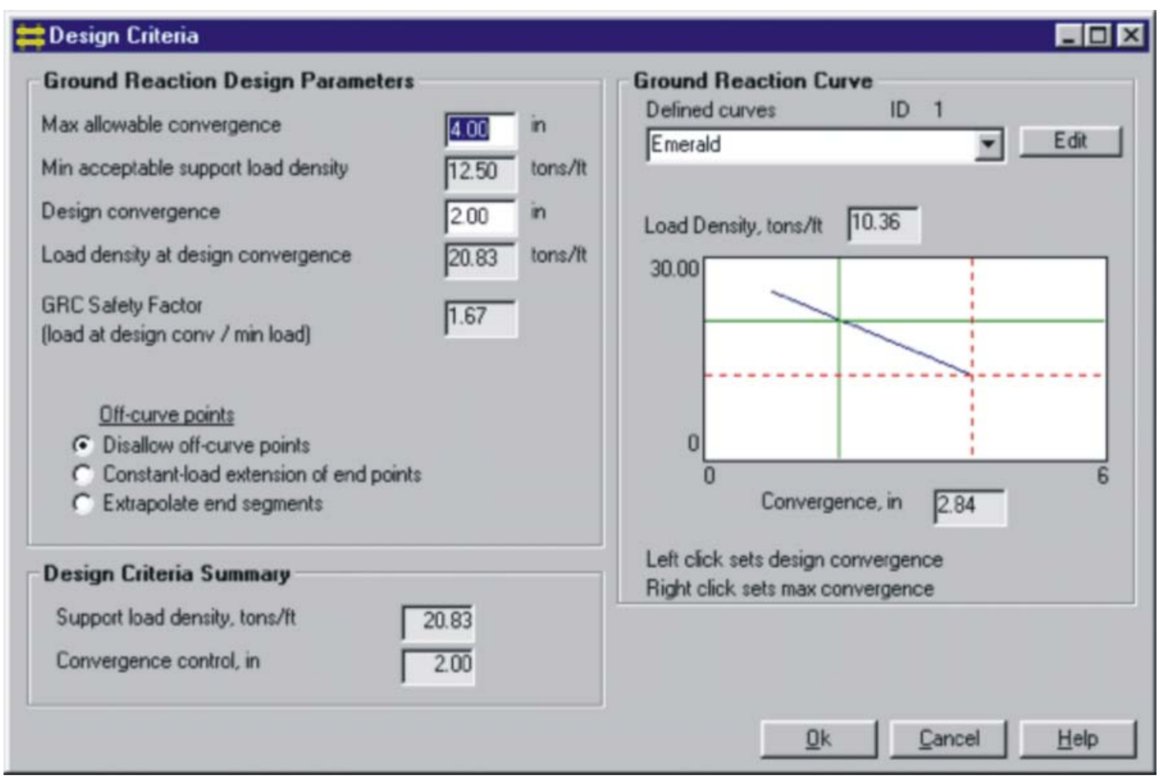

Figure 1.—Window for establishing design criteria based on ground reaction curve .

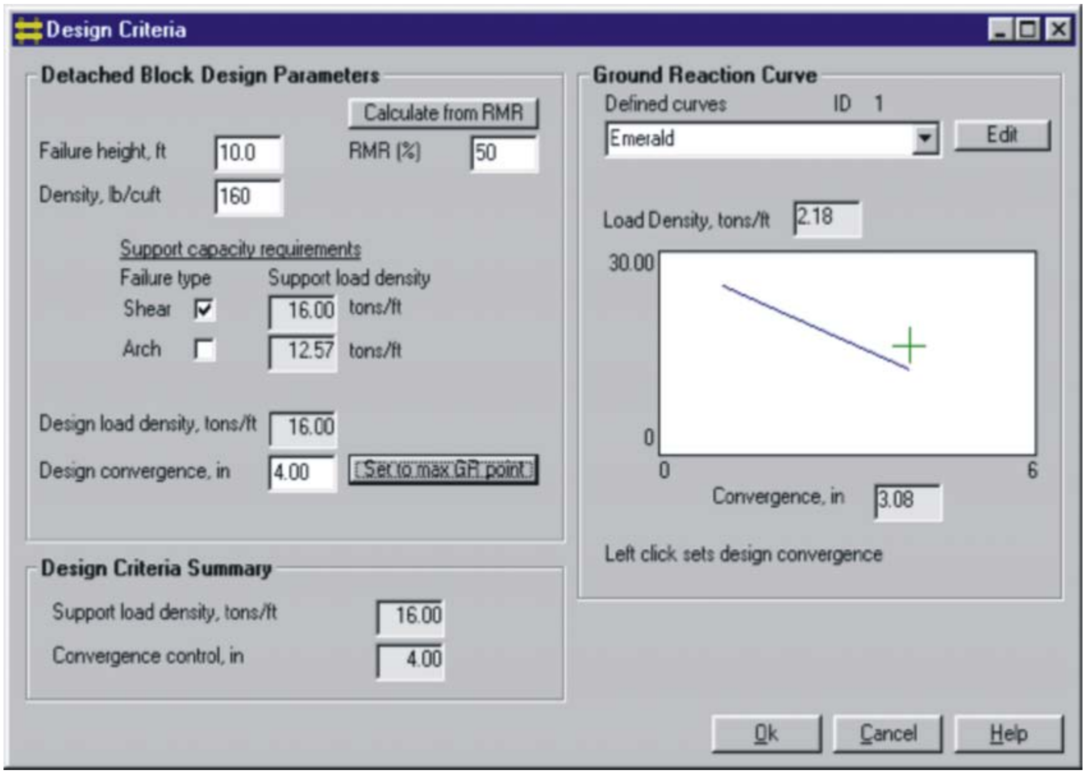

Figure 2.—Window for establishing design criteria based on detached roof block.

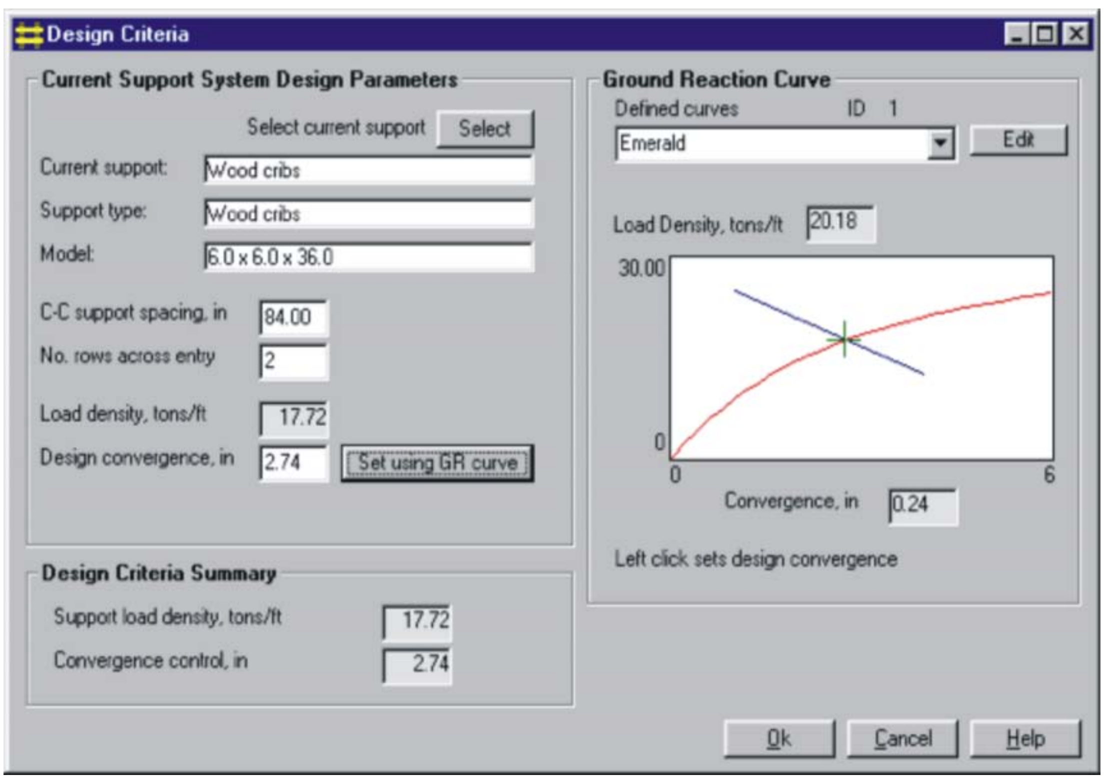

Figure 3.—Window for establishing design criteria based on current roof support system.

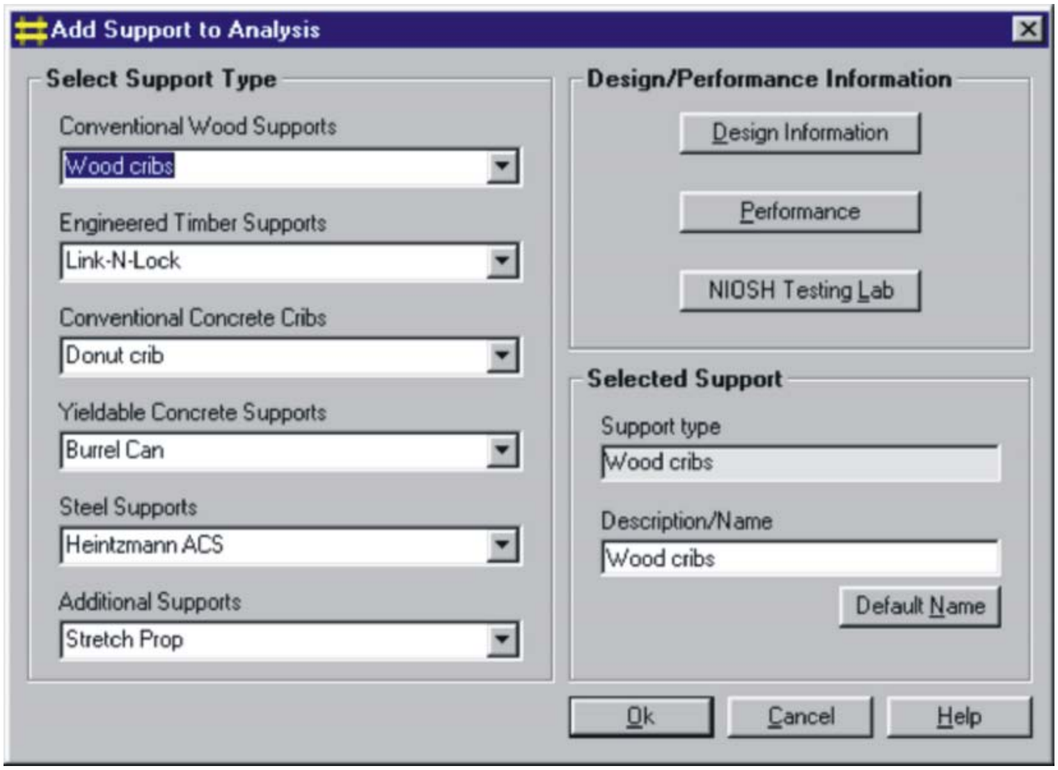

Figure 4.—Window for selecting support types for design and analysis.

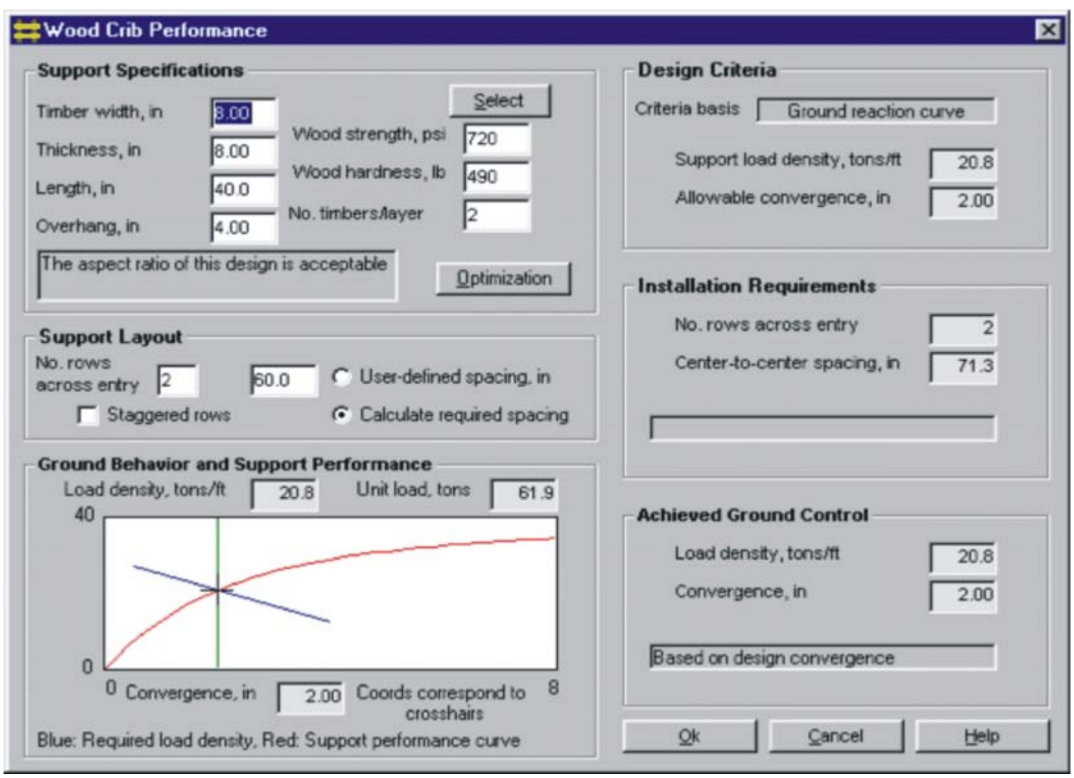

Figure 5.—Window for designing support system and determining installation requirements to achieve design criteria objectives.

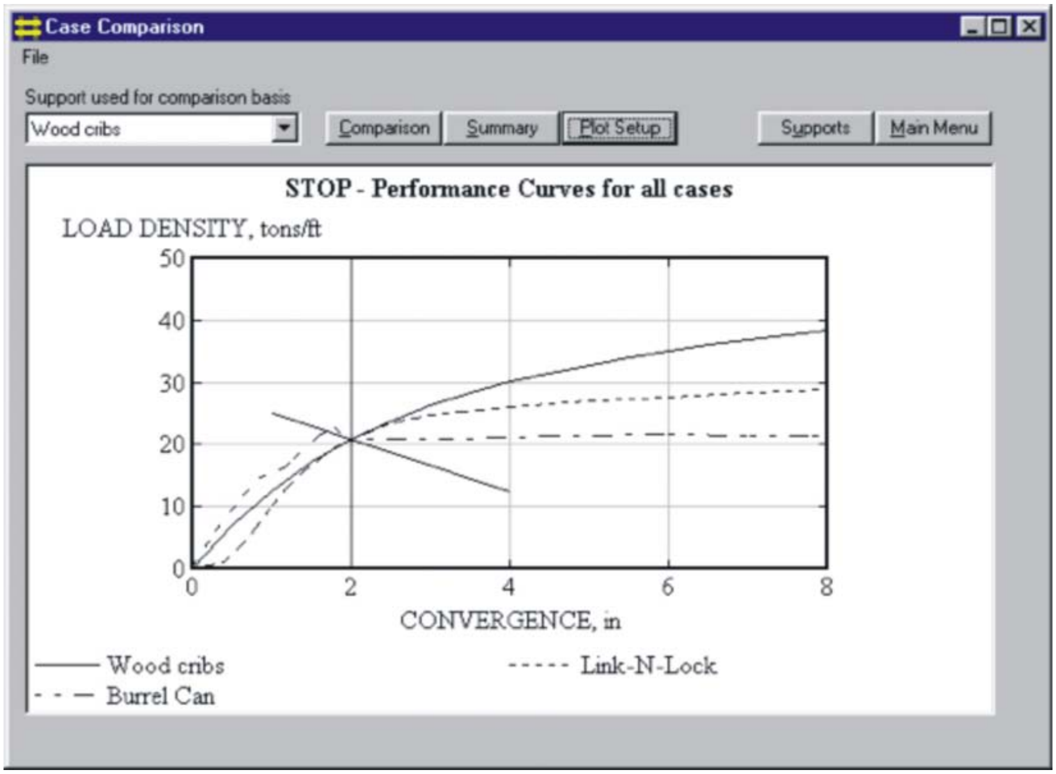

Figure 6.—Graphical analysis of selected support systems showing support load density as a function of convergence.

concrete crib supports, (4) yieldable concrete supports, (5) steel supports, and (6) additional supports. From this list and the embedded submenus, the user can select a specific support and learn more about the support through several other program buttons. *Design Information* provides a description of the support, design and installation considerations, performance characteristics, and manufacturer or supplier contact information. *Performance* displays the loading profile of the support with photographs that depict deformation and associated support loading. *NIOSH Testing Laboratory* describes PRL's Mine Roof Simulator and refers to the safety performance testing protocols through which the performance characteristics of the support were determined. *Reference/Bibliography* contains relevant reference material pertaining to the selected support system.

Help: A context-sensitive *Help* file is available to facilitate operation of the program and interpretation of the results. The *Help* file can be called from each window or from the main menu.

HOW TO USE STOP

Generally, the program control guides the user through a logical sequence of operations to facilitate the design and implementation of a roof support system (figure 7). A General Program Flow window is shown on startup. This window shows the basic program flow and recommends using the *Next* buttons to assist the user in following this recommended procedure for support design and analysis. The *Next* button transfers control to the *Design Criteria* module, where the user must select the basis for establishing the design criteria by choosing one of the following options: (1) ground reaction curve, (2) detached block, (3) current support system, or (4) arbitrary criteria. Control is then transferred to the appropriate window for the chosen design criteria and the user then defines the support load density and convergence design criteria in that window.

Once the design criteria are established, control is transferred to the *Select Supports* window. Here the user picks the supports to evaluate. Several options are available: (1) *Add* allows the user to select a new support and review the NIOSH database on support performance and design considerations, (2) *Delete* deletes a support from consideration, (3) *Duplicate* duplicates the choice of a support, which can be helpful when the user wants to reevaluate a support design with a few minor changes, and (4) *Rename* simply renames the support.

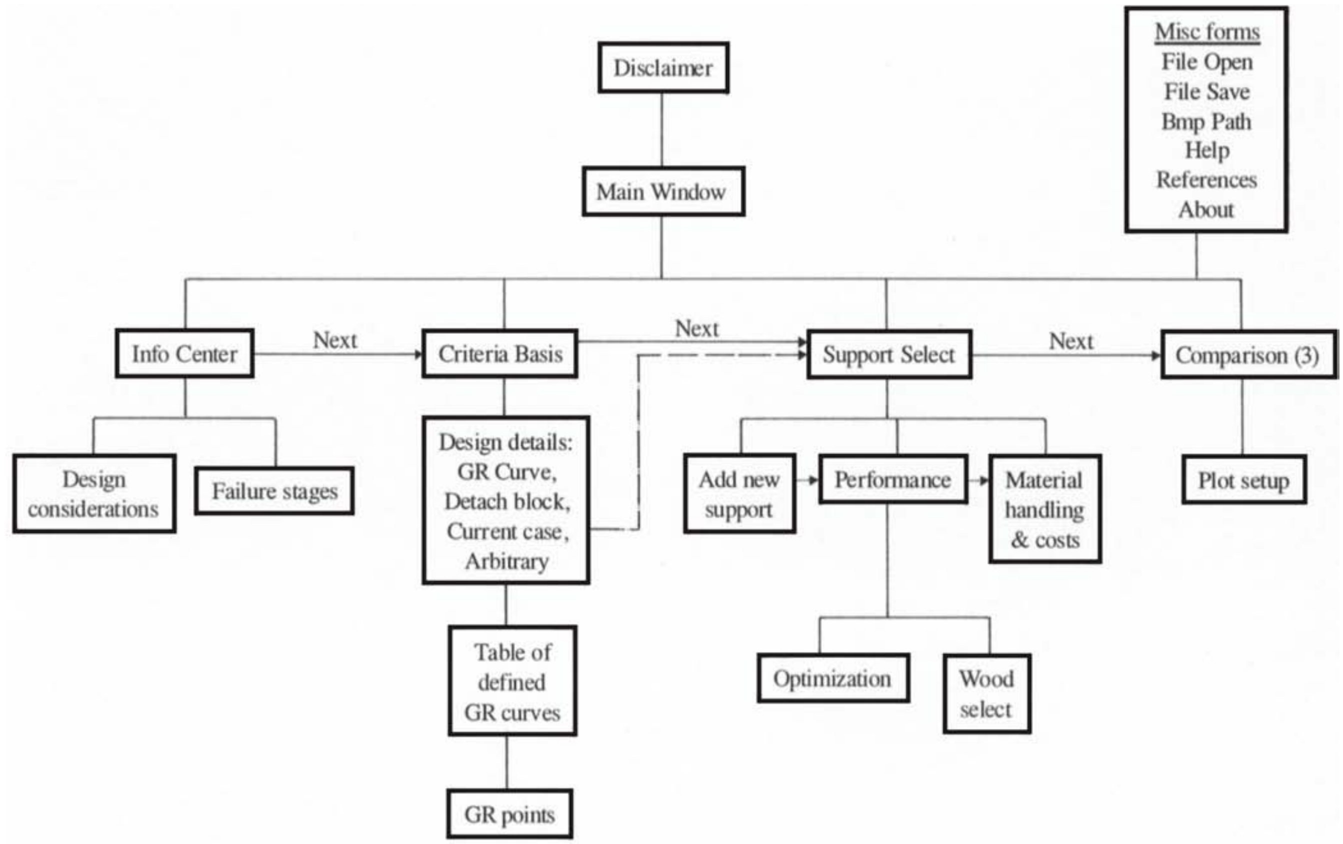

Figure 7.—Flow diagram showing program control.

After a support type is selected, control is transferred to a window where the user can define the appropriate support design parameters. Once the user defines the support design, the program calculates two outputs: (1) *Achieved Ground Control,* where support load density and the convergence control provided by the support system are displayed, and (2) *Installation Requirements*, where the number of rows and required support spacing are provided. For most supports, under *Support Specifications,* there is also an *Optimization* button. Clicking on the *Optimization* button causes the program to transfer to an optimization window where the user can select a support spacing and number of rows and the program will calculate the support model or design that most closely matches the required convergence and support load density previously established in the design criteria. The output of the optimization algorithm depends on which spacing option was selected in the support specifications window. If the "Calculate the Required Spacing" option is selected, the optimization routine will select a support design that will meet the design criteria at less than the specified maximum spacing. If the "User-Defined Spacing" option is selected, the program will determine a support design that will meet the load density requirement at a convergence less than the design convergence.

Once the support system is defined and the installation requirements (number of rows and spacing) are determined, control is transferred to the *materials handling* window where the support costs and material handling requirements can be defined and examined. A set of default values are included in the program that are considered to be representative of the various support technologies at the present time; however, the program allows the user to modify any of these parameters. In particular, the cost parameters may be mine-specific and time-dependent to some degree. These default values will be updated periodically when STOP is eventually placed on the NIOSH Web site (www.cdc.gov/niosh); however, the user should contact the support manufacturers to receive the latest cost information. Finally, the *Next* button transfers control to the *Comparison* module, where the various support systems can be compared to one another.

EXAMPLES OF APPLICATIONS OF STOP

EXAMINING THE LOADING PROFILE OF A SUPPORT SYSTEM

In the *Information Center* of STOP, photographs of each support during its loading phases are shown when the *Performance* button is clicked. The load-displacement curve for the support is shown with a vertical line to designate the displacement that corresponds to the photo in the window. Photos are typically shown at 2-in increments in support displacement. An example for the Propsetter support is shown in figure 8.

OPTIMIZING THE USE OF CONVENTIONAL WOOD CRIBS

Historically, conventional wood cribs have been used extensively for secondary roof support. A common support system is a double row of 4-point cribs constructed from 5- by 6-in (cross-sectional dimensions), 30-in-long, mixed hardwood timbers. STOP can be used to evaluate alternative designs and show that 9-point cribbing can be more cost-effective. The procedure to conduct such an analysis would be as follows:

1. Choose *Current Support Systems* as the basis for selecting the design criteria. Change entry height to 84 in for this example. Since no supports have been defined yet, click on the *Add* Option to transfer control to the *Add Supports to Analysis* window, where wood cribs can be selected and relevant information on the design and performance of wood cribs can be reviewed. *OK* then transfers control to the *Wood Crib Specifications* window.

2. In the *Wood Crib Specifications* window, enter the wood crib specifications (timber width, timber thickness, timber length) and select the mixed hardwood species to establish wood strength. Input the number of timbers per layer. After confirming the support design, *OK* transfers control to the *Select Current Support* window. *OK* then transfers control to the *Design Criteria* window, where the current wood crib design is featured.

3. Enter a value for the spacing of the supports, number of rows, and a convergence to establish the support load density design criteria. In this example, a spacing of 81 in for a double row of cribs and a convergence of 4 in were chosen. *OK* transfers control to the *Select Basis for Design Criteria* window, where the support load density requirements of 10.6 tons/ft and convergence control of 4 in are displayed. When these values are confirmed by pressing *Next*, the *Select Support* window is recalled. The user is required to update this design by activating the *Design and Cost* button before proceeding. When the *Design and Cost* button is pressed, control transfers to the *Wood Crib Performance* window, where the *Installation Requirements* and *Achieved Ground Control Parameters* are displayed.

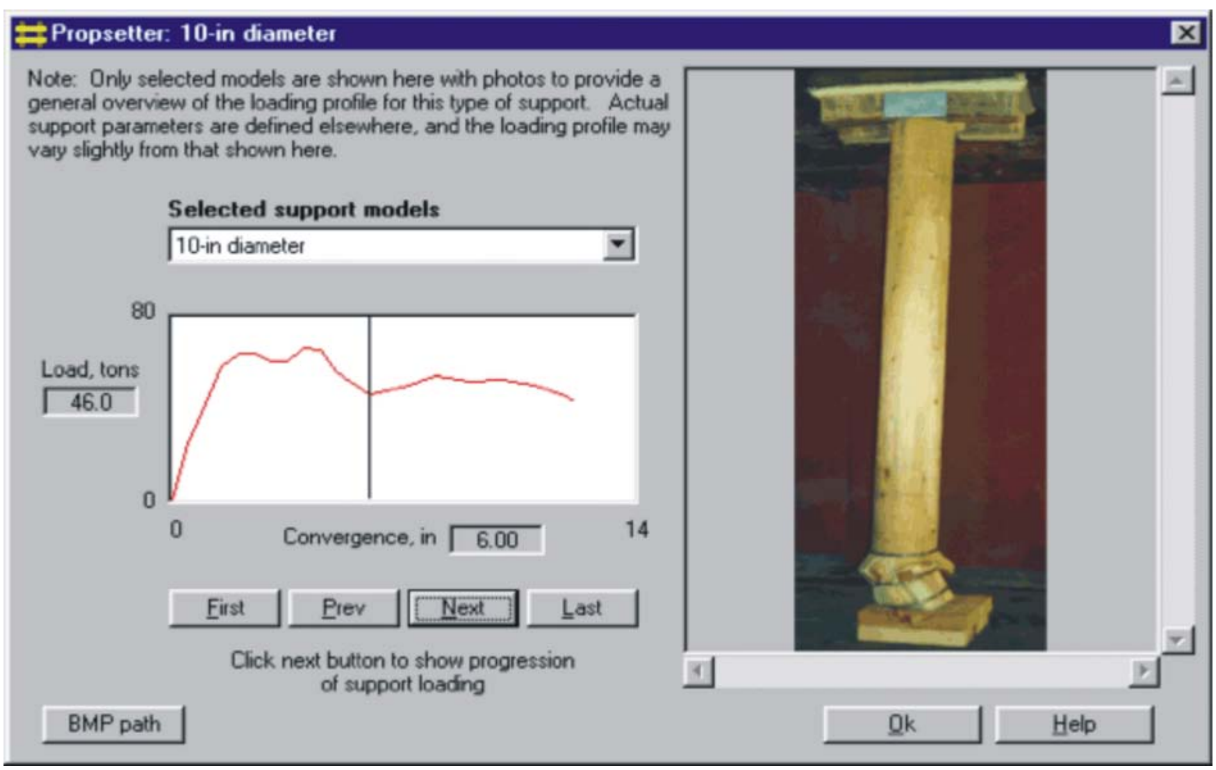

Figure 8.—Example of load profile display available in Information Center module.

4. The support material handling and costs for this crib design are then examined by pressing the *OK* button.

5. When control transfers back to the *Select Supports* window, the 9-point crib can be analyzed. One way to accomplish this is to duplicate the current support (press *Duplicate* button and then the *Design and Cost* button) and simply change the number of timbers per layer from 2 to 3 and the number of rows from 2 to 1. The program will then calculate the required spacing of single row of 9-point cribs that will provide the same load density as that of the double row of 4-point cribs.

Figure 9 documents the result of one such analysis and shows a comparison of the installed cost of a double row of 4-point cribs on an 81-in center-to-center spacing with that of single row of 9-point cribs on a 92-in spacing. Both support systems, using cribs constructed from 5×6×30-in mixed hardwood timbers, provide 10.6 tons/ft of support capacity at 4 in of convergence. Also included in this analysis is a double row of 4-point cribs constructed from all oak timbers instead of mixed hardwoods. Note that in this analysis, the narrow (5-in) side of the timber was placed down to establish the interlayer contact.

Figure 10 illustrates the same comparison, except that the cribs are constructed with the wide (6-in) side down instead of the narrow (5-in) side down, as was done in the previous example. The results clearly show the benefits of maximizing support capacity by increasing the contact area using the wide-side-down construction.

REPLACING CONVENTIONAL WOOD CRIBBING WITH ENGINEERED TIMBER SUPPORTS

In recent years, numerous alternative timber supports have been developed. These supports are engineered to provide improved loading characteristics compared to conventional wood cribbing. For this example, the goal is to replace a conventional wood crib design with engineered timber supports and provide equivalent support capability in terms of support load density at a specific convergence. The procedure for designing these engineered timber supports is essentially the same as in the previous example, except that alternative supports are chosen for analysis instead of conventional wood cribs.

The baseline case for this example is the same as that chosen in the previous example: a double row of 4-point, mixed hardwood cribs constructed from 6×6×36-in timbers on 116-in spacing providing 10.52 tons/ft support capacity at 4 in of convergence. The alternative supports chosen for this example were (1) 24-in Link-N-Lock, (2) 30-in Link-N-Lock, (3) Hercules HM-9(308) crib, and (4) 30-in Tri-Log crib. Figure 11 shows the installed support cost per foot of entry for support systems designed by STOP to provide equivalent support loading to that of the conventional wood crib support system chosen as a baseline. The installation requirements are also shown. As seen in figure 11, all four of the engineered timber support systems are able to reduce the installed support cost considerably without sacrificing support capability.

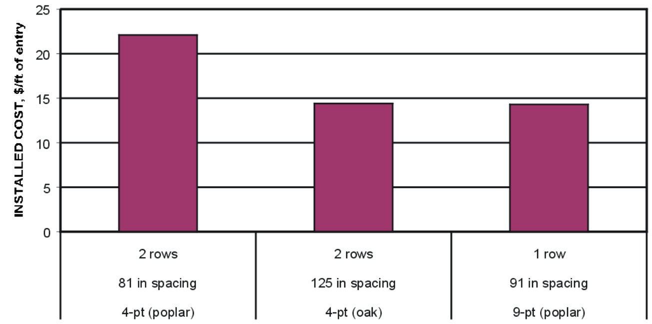

Figure 9.—Comparison of installation costs of various wood crib designs (timbers are 5×6×30 in and placed with 5-in side down).

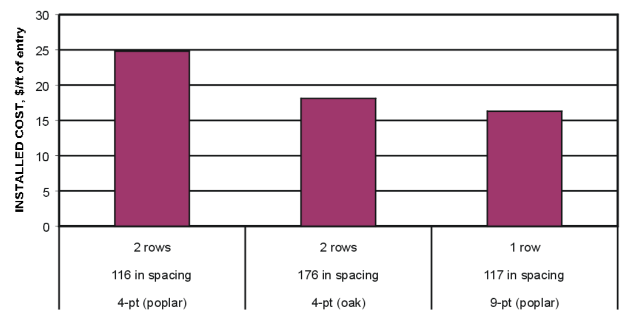

Figure 10.—Same analysis as shown in figure 9 except wide (6-in) side of timber placed down.

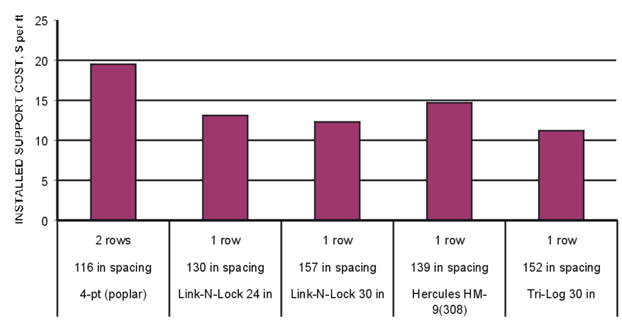

Figure 11.—Evaluation of engineered timber support systems as a replacement for conventional wood cribbing.

INCREASING SUPPORT LOAD DENSITY TO REDUCE ENTRY CONVERGENCE

The objective of increasing support load density is to improve ground control by allowing less roof movement. If the ground reaction at a particular mine is known, then support systems can be designed to provide any measure of convergence desired. The following example (figure 12) is based

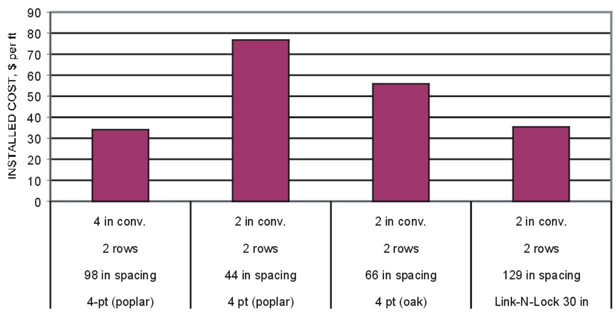

Figure 12.—Analysis of support system options when convergence requirement is reduced from 4 to 2 in.

on a ground reaction curve selected from the program's database. Using this curve, convergence is reduced from 4 in, achieved with two rows of conventional 4-point, mixed hardwood cribs on an 87-in spacing, to 2 in with alternative supports.

1. Choose *Ground Reaction Curve* as the basis for selecting the design criteria. Change the default entry height from 96 to 84 in. In the Ground Reaction form, the Emerald ground reaction curve is chosen. Input 4 in for the design convergence, and the program will determine the required support load density consistent with the ground reaction curve. In this case, it is 12.50 tons/ft.

2. Control will then be transferred to the *Select Supports* window. Pressing the *Add* button brings up the *Add Support to Analysis* window. Choose wood cribs as the support type.

3. Control will then be transferred to the *Wood Crib Performance* window, where parameters for a 4-point wood crib are defined (6×6×36-in timbers, mixed hardwood species, two rows, two timbers per layer). The program will then determine the installation requirements for this crib design as a 98.5-in spacing of the support. The program proceeds to the *Costs and Material Handling-Wood Cribs* window. Review the default settings for wood crib. The program then computes an installed cost per foot of entry for this support design.

4. Control is then transferred to the *Case Comparison* module. Review the performance parameters for this support system.

5. The *Comparison* window is then closed by transferring control back to the *Main Menu*. Activate *Design Criteria* and edit the *Ground Reaction Curve* design criteria (Emerald Mine) by changing the design convergence to 2 in. A warning message will be displayed, which indicates that the design criteria have changed. The 4-point wood crib system must then be updated by pressing the *Design and Cost* button. The installation requirements for this crib support system are changed to 44 in for the new design criteria.

6. Control will then be transferred back to the *Select Supports* window. Select one of the various alternative support technologies for analysis and enter the appropriate design parameters in the *Performance* window.

7. When the support designs are completed, the *Case Comparison* window will show baseline wood crib performance at 4 in of convergence and the alternative support performance at 2 in of convergence.

REPLACING TIMBER SUPPORTS WITH OTHER ALTERNATIVES

There are several alternatives to timber supports. STOP can be used to evaluate these various alternatives and make comparisons based on equivalent support capability or show the advantages of alternative placement strategies with superior roof support systems. The following example shows how these alternative support technologies can be designed relative to the current roof support system using available ground reaction data.

The process begins by selecting the *Current Support System* for design basis. The entry height is left at the default setting of 96 in. In this example, the current roof support system is a double row of 4-point wood cribs. Thus, the user selects wood cribs as the support type and enters the appropriate data in the *Wood Crib Specifications* form to define a 4-point crib constructed from 6×6×36-in timbers oak timbers. The center-to-center support spacing (108 inches in this case) and the number of support rows (two in this case) are entered. Design convergence and support load density are determined by clicking on the *Set Using GR Curve*, where it is shown that the current support system intersects the chosen ground reaction curve at 3.34 in of displacement and provides a support load density of 15.25 tons/ft. Table 1 compares several alternative support systems that provide equivalent or improved support capability. It is noted that with some supports, the support may shed load prior to the design convergence. The program logic is set to use the design convergence, but the user can determine from the ground behavior and support performance curves the convergence at which these supports will provide the required load density (see example in table 1).

USING OPTIMIZATION ROUTINES TO SELECT BEST SUPPORT DESIGN

The previous examples have shown how STOP determines the required support spacing needed for a user-specified support design. The optimization routines allow the user to specify support spacing and number of rows of support elements, and the program will determine which support design best fits the load and convergence design criteria. In the example shown in table 2, the design criteria of 16.67 tons/ft of entry at 3 in of

Table 1.—Comparison of alternative support technologies as replacements for conventional wood cribbing

Support type	Design specifics	Installation requirements		Achieved convergence control, in	Achieved support load density, tons/ft
		No. of rows	Spacing		
Wood cribs	4-point (6×6×36-in oak timbers)	2	108	3.34	15.2
Pumpable crib	30 in	1	73	3.34 [1](0.24)	15.2
ACS	Pizza headplate	2	92	3.34 [1](1.51)	15.2
Can	24-in-diam	2	138	3.34	15.2
Stretch prop	Timber ft/hd boards	3	61	3.34	15.2

NOTE: Design requirements: support load density = 15.25 tons/ft; convergence = 3.4 in.
[1]The required support load density of 15.2 can also be achieved at less displacement since the support sheds load prior to the design convergence of 3.34 in. Using the mouse coordinates on the ground behavior and support performance curve in the appropriate support design window, the convergence that produces the required 15.2 tons/ft of loading can be determined.

Table 2.—Support systems determined by the optimization routine for user-defined support installation parameters

Support type	Optimized design	User-specified installation requirements		Achieved convergence control, in	Achieved support load density, tons/ft
		No. of rows	Spacing		
Wood cribs . .	9-point (5×5×30-in timbers)	2	96	2.8	17.6
Link-N-Lock	36 in	1	96	2.6	18.5
Tri-Log cribs	30-in standard	2	96	1.5	23.0
Propsetter . . .	10-in-diam	2	96	2.6	18.4
Can	24 in	2	96	1.6	22.5

NOTE: Design requirements: support load density = 16.67 tons/ft; convergence = 3.0 in.

convergence were established from a ground reaction curve chosen from the program database. A 96-in spacing was chosen for the analysis by entering 96 inches in the *Support Layout* section for the user-defined spacing option. Then various support types can be selected for evaluation. When the *Optimization* button in the *Performance* form is selected, the user will define the installation requirements (number of rows and support spacing), and the program will determine the support model that most closely matches the design criteria (16.67 tons/ft at 3 in of convergence). Since the installation spacing and number of rows are specified, the achieved convergence will vary depending on the support type chosen. Table 2 documents some examples of optimized supports as determined by STOP.

EVALUATING MATERIAL HANDLING ASPECTS OF SUPPORT DESIGN

Surveillance data show that material handling injuries are common in support construction, resulting in several thousand lost workdays each year. Thus, part of the support selection process should be material handling requirements. Figure 13 is an example of data derived from STOP for four support systems: (1) pumpable crib, (2) Alternative Crib Support (ACS), (3) Propsetter, and (4) conventional 4-point crib. As seen from this analysis (figure 13), there are significant material handling advantages in using the alternative support technologies instead of conventional wood cribbing.

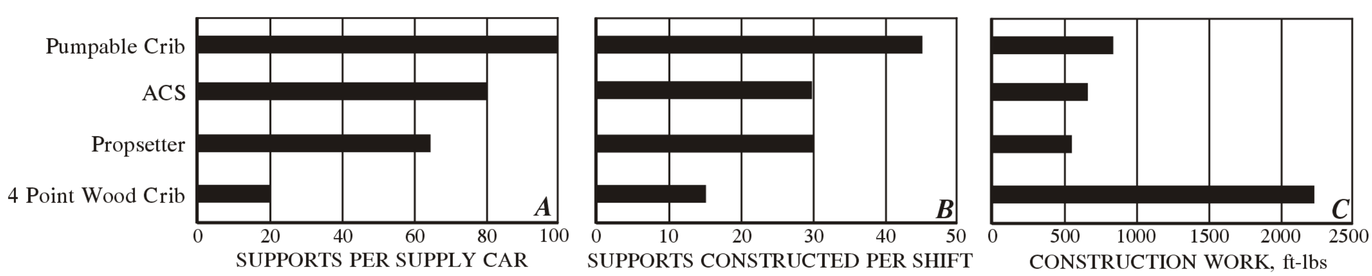

Figure 13.—Comparison of conventional wood supports with three alternative support systems. *A*, Number of supports per supply car; *B*, number of supports constructed per shift; and *C*, amount of construction work in foot-pounds.

CONCLUSIONS

Historically, wood cribs have been used as secondary roof support in underground mines. The Wood Crib Performance Model was developed in 1994 to provide an engineering foundation for the design and applications of these supports. In the past few years, many new support technologies have been developed by various roof support manufacturers. In many cases, these innovative support technologies provide superior roof support and reduced material handling requirements. However, each has its own performance characteristics; thus, they all need to be employed differently to provide equivalent roof support.

STOP was developed to provide a more comprehensive support design program than that provided by the original Wood Crib Performance Model. Not only does STOP include new support technologies, it also allows for application of a new design methodology based on a measured ground reaction curve at a particular mine site. Also included in STOP are a comprehensive material handling assessment and cost evaluation for each support system. STOP is a Windows-based program that is user-friendly and very flexible and provides engineering solutions for various secondary support applications.

STOP can be used to determine installation requirements for an alternative support technology that will provide equivalent support compared to a mine's current support system or an installation that will provide a specified support load density at a designated roof convergence. The optimization routines in the program will select the most efficient support design for the user-specified criteria.

STOP uses performance data developed by NIOSH through safety performance testing in the Mine Roof Simulator. Each support system has been evaluated through a rigorous testing protocol that simulates in-mine service conditions. Photographs of support conditions at various stages of loading are also included in STOP. These photos help the user gain an understanding of the limitations of the support and can be used to assess general loading conditions when these profiles are observed underground.

STOP can provide some much-needed engineering for secondary roof supports. This can be very helpful when petitioning MSHA for approval to use an alternative support technology or changing applications, such as increasing support spacing. By proper engineering of the support relative to ground reaction, convergence can be controlled to a predetermined level. This will allow an operator to optimize the support application and provide a margin of safety in roof stability that will reduce the likelihood of roof failure without the need for excessive roof support. Likewise, proper engineering will remove uncertainty in support design and prevent the application of inadequate support that can lead to roof falls. Finally, STOP will allow mine operators to consider fully the material handling aspects of support design in the selection process, thereby reducing the incidence and severity of material handling injuries.

Copies of the STOP software program can be obtained from Thomas M. Barczak, NIOSH Pittsburgh Research Laboratory, P.O. Box 18070, Pittsburgh, PA 15236-0070; phone: (412) 386-6557; e-mail: TBarczak@cdc.gov. It is also anticipated that STOP will eventually be available through the NIOSH Web site (www.cdc.gov/niosh).

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